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NEPTUNE ORBITER

Robert Gershman, Erik Nilsen, and Richard Wallace
Members of the Technical Staff
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

ABSTRACT

This paper describes the results of a study to update the concepts for the exploration of Neptune to reflect the latest projections for spacecraft technology developments within the next several years. The overall science goals of the Neptune Orbiter Mission are presented, as well as the baseline instrument set needed to accomplish the objectives. A minimum energy transfer from Earth to Neptune would require more than 30 years, which is too long for a planetary mission. For this study, a ten year transfer time to Neptune was established as a constraint. Key features of the spacecraft design include an aerocapture ballute, an advanced radioisotope power source and Solar Electric Propulsion. The mission design is consistent with the capability of launch vehicles in the Delta IV/Atlas 5 class.

INTRODUCTION

In cooperation with NASA's Solar System Exploration Subcommittee and its working groups, JPL is investigating the feasibility of planetary science missions proposed for launch during the next decade. Results will be used to focus resources on developing technology that will enable a set of missions in which meeting severe technological challenges will be rewarded with extraordinary scientific advances and lower cost missions. The Neptune Orbiter mission described here clearly fits this description. Being able to reach and operate at Neptune (30 AU) will provide us with opportunities to develop substantial new insights into the formation of planetary systems. The mission options described were developed by the Astrophysical Analogs CSWG and JPL's Team X[1].

SCIENCE OBJECTIVES AND MEASUREMENTS

The overall science goals of the Neptune Orbiter Mission are to study the rings, ring arcs, and shepherd satellites over at least 2 years; map Triton's surface features, examine its geologic history, surface composition, and internal structure, and monitor its atmosphere and seasonal cycles; examine the composition, structure and dynamics of Neptune's atmosphere; probe Neptune's magnetosphere with extended temporal and spatial sampling; and image and determine the densities of the satellites Larissa, Proteus and Nereid.

Science Objectives

1. Rings and ring-region satellites:
   - Refine and monitor orbital elements of the rings (particularly the ring arcs) and the inner satellites through at least 2 years, looking for unexpected or predicted changes over time.
   - Understand the details of the interactions between rings and satellites. Characterize the inner ring/satellite system; search for new satellites and new rings which cannot be detected from ground-based observations or HST/Nicmos.
   - Examine the morphology of the ring arcs/Adam's rings. Look for embedded bodies and Lagrange satellites.
   - Investigate surface processes of ring-region satellites. Examine crater ejecta patterns and fracture patterns (perhaps similar to those seen on Phobos and Deimos).
   - Determine the composition of the rings and, if possible (at low phase), the composition of embedded bodies/Lagrange satellites. Determine the composition of ring-region satellites, looking for methane, water, carbon dioxide, other hydrocarbons, organics and silicates (particularly, the 0.9 and 1-μm bands of the silicates olivine and pyroxene).

2. Triton
   - Determine the physical properties and structure of the atmosphere (temperature, pressure, scale height), including any variation with latitude.
   - Determine the composition of the atmosphere, including local variations arising from erupting geysers, and the abundance and distribution of aerosols.
   - Determine the global distribution of volatiles, including the presence of a north polar cap.
   - Map surface temperatures to identify the sources of volatiles in the atmosphere.
   - Characterize surface geologic processes, including tectonic activity, volcanic/geyser activity, glacial activity, subsidence, processes of erosion and degradation, and processes affecting crater morphology.
   - Map surface compositions, searching for correlations between particular geological and compositional units.
   - Determine the internal structure and size of tidal distortions.
   - Search for the presence of an induced or intrinsic magnetic field.
   - Search for changes in orbital eccentricity.

3. Other Satellites
   - Determine the density (mass), composition, and gross geologic history of the satellites Larissa, Proteus, and Nereid.

4. Neptune
   - Map the three-dimensional atmospheric circulation pattern with depth.
   - Map Neptune's temperature field and refine the value of its internal heat flux.

- Search for extreme changes in the atmosphere over time (as indicated by HST-based observations).
- Map convection patterns and, if present, zonal circulation patterns at depth in thermal emission.
- Map the three-dimensional compositional structure of the atmosphere, including the upper atmosphere where aerosols are likely produced.
- Determine the composition of deep atmosphere/interior, including the H/He, isotopic compositions, etc.
- Map the higher moments of the magnetic field.
- Map the higher moments of the gravity field to determine internal mass distribution.
- Measure the populations and energies of magnetospheric constituents to understand the energy inputs to both the upper atmosphere of Neptune and the surface/atmosphere of Triton.

<u>Measurement Objectives</u>

1. Rings and Ring-Region Satellites
    - Imaging resolutions of at least 1 km on rings and satellites for orbital determination, monitoring and for mapping satellites.
    - Low-phase, high-resolution (100-m) imaging of ring arcs to search for arc-embedded bodies and for compositional determination of such bodies.
    - High-phase imaging searches at 1-km scale for detection of new rings and/or arcs and for characterizing ring/arc morphology.
    - Compositional determination of larger ring bodies and of both known and new satellites, with the ability to distinguish CH_4, CO_2, silicates, C-H bonds, etc.
    - Multiple occultations of radio telemetry signals for ring-structure and particle-size characterization.

2. Triton
    - Global imaging at resolutions of <100 m from UV to near IR, especially the polar regions. (Dark side may be visible in Neptune-shine.)
    - Very high resolution imaging (10s of m/pixel) of specific locations at different latitudes, including the south polar cap region.
    - Global-imaging spectroscopy from 1 to 5 μm at resolutions of 1 km.
    - Multiple occultations of radio telemetry signals for atmospheric structure.
    - Multiple UV (stellar or solar) occultations of Triton's atmosphere to determine density, scale height, temperature and composition.
    - Imaging of limb at high phase to detect hazes and plumes.
    - Thermal mapping of Triton's surface at 50 and 100 μm.
    - Direct sampling of the Triton's upper atmosphere

3. Other Satellites
    - Global mapping at resolutions of 100 m of Proteus and Larissa; imaging at resolutions of 100 m of Nereid, if possible.
    - Composition and mass of Proteus, Larissa, and, if possible, Nereid.
    - Orbital refinement of all of the small satellites.

4. Neptune
    - Thermal mapping of the entire planet at various phase angles.
    - Compositional mapping of the entire planet
    - Repeated, simultaneous narrow-and wide-angle imaging to capture atmospheric motions and measure winds. Narrow-angle imaging scales can be 10 km.
    - Measurement of the magnetic field and magnetospheric particles at a variety of latitudes and longitudes in the rotating (magnetic) coordinate system.
    - Multiple occultations of radio telemetry signals for atmosphere to ~ 2 bar level.
    - Multiple UV (stellar or solar) occultations of Neptune's atmosphere to determine density, scale height, temperature and composition.

<u>Science Implementation</u>

The strategy for data collection at Neptune includes the following:

(1) Approach coverage—atmospheric monitoring of Neptune and a Nereid flyby.

(2) Capture phase – accelerometer and fields and particles data.

(3) Orbital science phase – repeated flybys and observations of Neptune, Triton, the rings, and Proteus and Larissa fields and particles measurements.

The orbital science phase should last at least 2 years (3 years are desired) in order to monitor changes on Triton and within the atmosphere and magnetosphere of Neptune. During this phase, the following geometries are required:

- Closest approach flybys of Triton at altitudes ~1000 km.
- Closest approach flybys of Triton at different phases in its orbit (i.e., different longitudes) and at different latitudes, including both poles.
- Very high phase (> 165°) viewing of Triton and the rings.
- Closest approach distances to the innermost satellites of ~ 1000,000 km at various phases in their orbits.
- Very close approach, low phase encounters with the ring arcs at ~ 10,000 km.
- Closest approach flybys of Neptune at a variety of latitudes.
- Low phase and contiguous Neptune observing from distances of ~38 Neptune radii.

Eight instruments were considered part of the baseline payload: a visible imager, an IR-imaging spectrometer, an UV-imaging spectrometer, a thermal-IR spectrometer, an ion-and-neutral-mass spectrometer, a magnetometer, a charged-particle detector and a plasma-wave spectrometer. A large range of sensitivity is desired for the thermal-IR spectrometer (25 to 100 μm) to combine the thermal measurement objectives for both Neptune and Triton. Radio occultation science was also included in the baseline, although its mass requirements and technology implications were found to be substantial.

MISSION DESIGN

A minimum energy transfer from Earth to Neptune would require more than 30 years, which is too long for a planetary mission. Each year trimmed from that time reduces the mass which any given launch vehicle can deliver to Neptune. Thus the flight time has to be chosen for programmatic reasons and then can be increased if necessary to allow more mass delivery. For this study, a 10-year transfer time to Neptune was chosen.

A number of alternatives to a direct transfer were examined[2]. A Jupiter flyby offers the most gain of the impulsive/ballistic trajectory alternatives; such a transfer is available for Earth departures in 2005, 2006, and 2007 and then not again until about 2017. An Earth gravity assist at the beginning of the transfer would further improve the mass delivery performance, but in order to combine this with a Jupiter gravity assist (JGA) the launch would have to be no later than 2005. A direct JGA transfer leaving in 2007 was selected for study.

Several SEP options were also considered, and the study focused on one using an indirect 10-year transfer to Neptune. An Earth gravity assist would improve the mass but was not considered because the spacecraft would be carrying a radioisotope power supply. The SEP system is based on advanced NSTAR technology and the solar arrays are sized for 24 kW (1 AU) in order to achieve a 10-year trip time with the baseline payload.

FLIGHT SYSTEM

Key features of the baseline design include an aerocapture ballute estimated at 18% of the entry mass, an Advanced Radioisotope Power System (ARPS) power generation system and general use of planned X2000 second or third delivery capabilities. The SEP systems operate at 24KW using Ultraflex arrays. The telecom system uses a 6 m "astromesh" antenna operating at both X and Ka bands to satisfy telemetry and radio science requirements. Adaptive feed and a beacon signal from Earth are used to provide the required precise pointing.

Subsystem masses for the baseline case studied by Team X are summarized in Table 1. The negative mass margin shown relative to the Delta III launch vehicle is not considered to be a serious problem because more capable launch vehicles (Delta IV, Atlas 5) are becoming available at similar cost.

Table 1. Mass Summary

SUBSYSTEM	MASS (kg)
INSTRUMENTS	15
BUS	
ACS	13
C&DH	3
POWER	34
PROPULSION	10
STRUCTURE	29
S/C ADAPTER	3
CABLING	7
TELECOM	26
THERMAL	6
TOTAL DRY S/C	**146**
CONTINGENCY	43
S/C WITH CONTINGENCY	**189**
PROPELLANT	37
TOTAL WET S/C	**226**
BALLUTE	41
SEP STAGE	
ACS	12
C&DH	1
POWER	289
PROPULSION	195
STRUCTURE	224
THERMAL	15
TOTAL DRY SEP	**736**
CONTINGENCY	151
SEP WITH CONTINGENCY	**887**
XENON	717
TOTAL SEP STAGE	**1604**
LAUNCH MASS	**1871**
L/V CAPABILITY (DELTA III)	**1826**
MARGIN	**-45**

TECHNOLOGY

Neptune Orbiter is a technology hungry mission. The mass estimates above are based on the following developments being successfully completed.

- AEROCAPTURE - using either a ballute (which is assumed here) or an advanced heat shield. A ballute-based aerocapture system was estimated at 18% of the total entry mass.
- NEPTUNE DELIVERY CAPABILITY - this mission needs improvements in SEP performance coupled with substantial cost reductions. Solar sailing may be an important alternative.
- COMMUNICATIONS - Work is needed on light weight antennas, adaptive feed, and interactions with ACS to confirm that both telemetry and radio science can be implemented in systems of affordable mass.
- POWER - Continued development of efficient ARPS capability and development of low-cost solar arrays for the SEP SYSTEM.
- MICRO-SPACECRAFT TECHNOLOGIES - Across-the-board advances are mandatory for a Neptune mission and were assumed in all options.
- DATA QUANTITY REDUCTION - A Neptune mission will utilize a combination of advanced data compression and autonomous selection of data for downlink to optimize science return.

COST

Based on Team X cost estimates the SEP option will total $400-$450M (FY99$). A ballistic (JGA) version could reduce the cost by $50-75M but is not available in 2008-2016.

CONCLUSIONS

The results confirm the implications of previous studies that reasonable technology advances will enable a comprehensive Neptune exploration mission (approaching Galileo or Cassini in scope) at costs potentially within reach of the Outer Planets program and significantly below the costs of Galileo and Cassini.

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